0010001	0010101	0010100
1001010	0101010	1010011
0011100	1125/60	1001010
1010101	1111010	0101110
0100100	1010010	1010010
0101010	1001001	1000100
1010000	1001010	0111101
1011110	0010101	1101010
1100101	0100101	1010010
0010010	0111010	1125/60
1001001	1010101	1010010
0010010	0101000	1001010
1001011	1110101	0101001
1001001	0101010	0101001
0010100	1110101	0100100
1125/60	0101010	1001001
1001010	1010101	0010010
1010101	1011101	1010101
0101110	0101101	0110101
1010010	0010001	0001001
1001010	0000100	0010101
0111101	1125/60	0101010
1101010	1001010	0101000
1010010	0011100	1111010
1010010	1010101	1010010
1001010	0100100	1001001
0101001	0101010	0100101
0101001	1010000	0010101
0100100	1011110	0100101
1001001	1100101	0111010
1125/60	0100100	1010101
0010010	1001001	1001010
1001010	0010010	1110101
0110101	1001011	0101010
0001001	1001001	1110101

BACKGROUNDER:

The 1125/60 Digital HDTV Production System and High Resolution Computer Generated Imaging:

Opportunities for Innovative System Integration

HDTV

1125/60

GROUP

HDTV 1125/60 GROUP

Moving images are no longer limited to the world of television and film and are now becoming a part of image processing applications. Propelled by the long established appeal and power of real world images, digital video images are appearing anywhere computer graphics are used: engineering workstations, personal computers, television and film post production, electronic pre-press, medical and industrial systems, etc.

Experienced, creative users of computer graphics can now integrate video signals and computer graphics to create powerful multimedia presentations. Scientists can analyze intricate sets of data through visualization techniques made possible by the seamless blending of graphics and imaging. Designers can expedite the examination of complex product concepts and designs. The list is endless.

However, although solutions for various system compatibility issues (necessary to establish a fully functional blend of computer imaging and video signals) have been in place at reasonable costs for some years now, a technical roadblock still exists in the integration of high resolution computer graphics/imaging and video signals. Conventional 525 and 625-line video signals continue to impose severe limitations (due to bandwidth and resolution constraints of its system components), in the storage, processing and display of images (either stills or moving sequences) with pixel densities in excess of 400,000 pixels.

This paper describes the current situation for the integration of computer and television images of conventional 525/625 standards. The application of the 1125/60 HDTV studio standard (SMPTE 240M) and its digital embodiment to transform the world of high resolution computer graphics for many uses for the scientific, entertainment (notably motion picture production), business and industrial marketplaces will be explained.

CURRENT SITUATION

The Integration of Video and Computer Imagery

In the world of computer graphics, it is now becoming common practice to process and store image files that have been generated by video equipment. The television industry, in turn, has made extensive use of computer-based graphics systems in the production and post-production of television programs (weather maps, news, sports, elections, etc).

It is the rapid, widespread growth of these practices that stimulates the continuing emergence of proven hardware and software tools to satisfy the system integration needs of multiple industries, each having quite different imaging requirements.

Broadly speaking, video signals (as currently found in the consumer and professional marketplace) share the following fundamental characteristics:

• Television captures the best full-motion images possible from live real-world scenes (using a highly complex analog optical-electronic transducer, the television camera imager) in real-time and under the constraints imposed by a wide range of lighting conditions.

• Current video equipment for the acquisition, processing, storage, and distribution of composite or component signals, makes use of interlace scanning with 525 or 625 lines and 30(60) or 25(50) frames (fields) per second.

• Although the studio television camera generates three full bandwidth signals (Red, Green and Blue), the storage and processing of this information often makes use of different sets of color components — such as luminance and color-difference signals.

Computer generated graphics and images, on the other hand, are the result of numerical calculations carried out in non-real time for the creation of still images or sequences of still images. These images typically are designed to satisfy viewing criteria that facilitate detailed and sustained viewing at short distances, on screens of modest size employing progressive scanning, and in the presence of controlled ambient lighting.

Despite the enormous differences that exist in the image generation process of computers and television, it is now possible to exploit the creative synergies of real-time image capture and synthetically generated images for complex still and full-motion images and graphics systems. Furthermore, neither imaging process — computer-based or video-based — needs to be sacrificed to satisfy technical constraints imposed by processing or display compatibility.

The rapidly advancing technologies of digital signal processing (in both hardware and software disciplines) and digital large scale integrated circuits enables — at the interface level — the digital conversion, scaling, interpolation, de-interlacing, and color transformations required to allow the bi-directional flow of computer and video-based images. Presently, there are several manufacturers of "board-level" computer-video interfaces that permit the analog and/or digital acquisition of component or composite interlace video signals. Once the digital video signal is "frame-grabbed", commonly available digital filtering software packages (and dedicated hardware realizations) enable the user to manipulate de-interlaced images that are geometrically correct. As always, however, there are tradeoffs between the effectiveness of the filtering algorithm and its execution time.

Due to advances in VLSI and digital video/image processing hardware, there has been a tremendous growth in computer systems that can offer features and capabilities found, until recently, only in professional television prod-

ucts. Among these capabilities are linear and non-linear editing, multi-layer compositing and special effects, paint systems, still-image data bases, multiframe frame grabbers, etc.

In addition, images that exist solely in the realm of the computer memory no longer need to be interpreted or processed following the rules of computer graphics. They can now be rendered to any output display/device format (taking into account picture and pixel aspect ratios, colorimetry spaces and interlace scanning). Hence, the rendered still-image becomes — at the level of the display or output buffer — a video signal for storage, processing or presentation utilizing conventional, off the shelf video equipment.

This effective utilization of the best and separately unique technical characteristics of the television and computer industries has led to a very fruitful, application-specific, integration of graphics terminals, workstations, digital storage devices (CD-ROM, M.O. and hard disk drives), videotape recorders, professional video equipment, and display/projection devices.

In some case, however, the low resolution of the computer's output frame buffer (such as in the case of VGA terminals) imposes some limitations in the picture quality (resolution, gray level and color gamut) of images for use in professional video applications. The converse is also very apparent, especially with recent dramatic cost reductions of high resolution, full color, computer workstations.

It is in these cases (i.e., high resolution imagery) that some pieces of the conventional video processing chain fail to provide the spatial-detail performance required for the seamless operation of the computer/video system. For those who work with high resolution imaging stations, it is a familiar situation, having to sacrifice the high quality of their synthetic images in order to make use of the storage and portability advantage of videocassette recorders of conventional television signals. Although it is true that current projection display systems perform quite reasonably when directly displaying high resolution images (such as 1280 x 1024 pixels, 8 bits per color), these images often have to be filtered down to lower resolutions for compatibility with component and composite videotape recorders, laserdisc, etc. It is indeed this technical constraint that creates one of the major impediments in the integration of high resolution imaging and video systems.

The introduction of the 1125/60 HDTV system for high-end program production has dramatically elevated television's capabilities. It is finally making possible the integration of high resolution computer imagery with television images of excellent spatial and temporal resolutions and color capabilities. It has been said that for the 90s and beyond, the 1125/60 HDTV system might well become a "hardcopy" medium for the high resolution computer industry.

ARRIVAL OF HDTV IN THE COMPUTER ENVIRONMENT

Characteristics of the Digital 1125/60 HDTV Production Format

From January 1984 through September 1987, the Working Group on High Definition Electronic Production (WG-HDEP) — operating within the Society of Motion Picture and Television Engineers (SMPTE) — directed a large effort toward formulation of a standard for HDTV program origination and exchange. An extensive representation from both the television industry and the motion picture industry participated in seeking an all-electronic HD origination system that would work synergistically with 35mm film to extend program production and distribution flexibility. From this work, an HDTV standard[1] finally emerged in 1988 — the SMPTE 240M 1125/60 HDTV origination standard.

To complete the digital characterization of the 1125/60 HDTV signal parameters, the WG-HDEP created, in October 1988, an Ad Hoc Group on Digital Representation of 1125/60. This group has also completed the stages of the standardization process. Even now, however, professional digital HDTV equipment (conforming to the recommendations of the digital standard, SMPTE 260M) is in use in the marketplace.

Early digital studies by the Advanced Television Systems Committee (ATSC) suggested structuring a scalable HDTV system that would facilitate convenient digital downconversion of HDTV originated programming to both the existing 525/60 and 625/50 standard television systems (as embodied in their digital representations, already specified in CCIR Rec. 601).

On this basis, the number of horizontal pixels dedicated to the active portion of the HD line was calculated according to:

$$720 \times 2 \times (16/9 \div 4/3) = 1920$$

That is, the HDTV picture would have twice the pixel resolution of 525/625 CCIR Rec. 601 standard (nominal 720) with a further pixel increase to correspond to the 1.33 extension in aspect ratio for HDTV (16:9 as opposed to standard 4:3 NTSC).

The number of active picture vertical lines were also chosen on the basis of scalability to the active line numbers of both the 525 and 625 television systems (483 and 575 respectively):

$$1035 \div 483 = 15/7$$
$$1035 \div 575 = 9/5$$

That is, 1035 active picture lines represented a number which can be factored to produce either 483 or 575. This has important considerations in the digital filter hardware implementation associated with interpolation in HDTV downconverters. Thus, the active raster of the SMPTE 240M picture frame consists of 1920 horizontal samples by 1035 vertical samples.

Digitization of the 1125/60 HDTV Signal

The Luminance sampling frequency has been chosen to be 5.5 times the well known value of 13.5 MHz of the CCIR Rec. 601. The HD Color Difference signals are sampled at half this frequency (similar to CCIR Rec. 601). Thus the following digital sampling frequencies are used for the digital signal processing of 1125/60 HDTV signals:

Luminance	Y	74.25	MHz
	P_R	37.125	MHz
	P_B	37.125	MHz

It should be noted that, for the 1125/60 HDTV standard, the sampling frequency value of 74.25 MHz offers an optimum compromise among many related, television-specific, parameters:

• Practical blanking intervals
• Total data rates for digital 1125/60 HDTV VTRs
• Compatibility with signals of the CCIR Rec. 601 digital hierarchy
• Manageable signal processing speeds

When considering the number of quantization bits for each component of the 1125/60 HDTV system, account has been taken of the extensive wordlwide implementation of CCIR Rec. 601. This has shown that 8 bits represented a very pragmatic compromise between reproduction of video dynamic range, signal to noise, invisibility of "contouring" and total data rate. The increas-

ing demands of the production and post-production community — for handling wider dynamic range signals and for multiple generations of signal processing (particularly for very high quality HDTV to 35 mm film transfers) — have also called for consideration of 10-bit (for future generations of digital 1125/60 equipment) as well as 8-bit quantization, per sample of the luminance signal and for each color-difference signal[2].

IMAGE GENERATION

Interlace-Progressive Scanning in HDTV Cameras, VTRs, and Display Devices

Despite the large number of recent technical advances in the processing capabilities of computers and application specific integrated circuits, the fact remains that there is an enormous, and for now a quite irreconcilable, difference between the image creation mechanisms of the computer and television industries.

However, once the visual information has been created (by computer or by television) in its digital electronic form and stored, there can exist reasonable potential for useful convergence within the digital domain of computers and television disciplines (see figure 1). And this is quite evident in all subsequent processing, storage, distribution and display of these electronic signals.

It is indisputable that interlace scanning can be unacceptable in certain high resolution computer displays. Many of these displays demand close viewing of complex and highly detailed images over sustained periods of time. This places special requirements on the design parameters of a display that will minimize image artifacts and human fatigue. Considerations of brightness, refresh rate, spatial resolution and progressive scanning, all enter into the performance decisions required to establish a satisfactory image portrayal for such critical viewing.

In HDTV, however, both the image creation mechanism and the human visual psychophysics are radically different. Here the attempt is to better emulate the expanded field of view which is normal to human vision as we view the real world around us. The very goal of HDTV is to achieve image portrayal that is a closer approximation to real life — an attempt to display a greater sensation of reality than that possible with current 525 NTSC equipment.

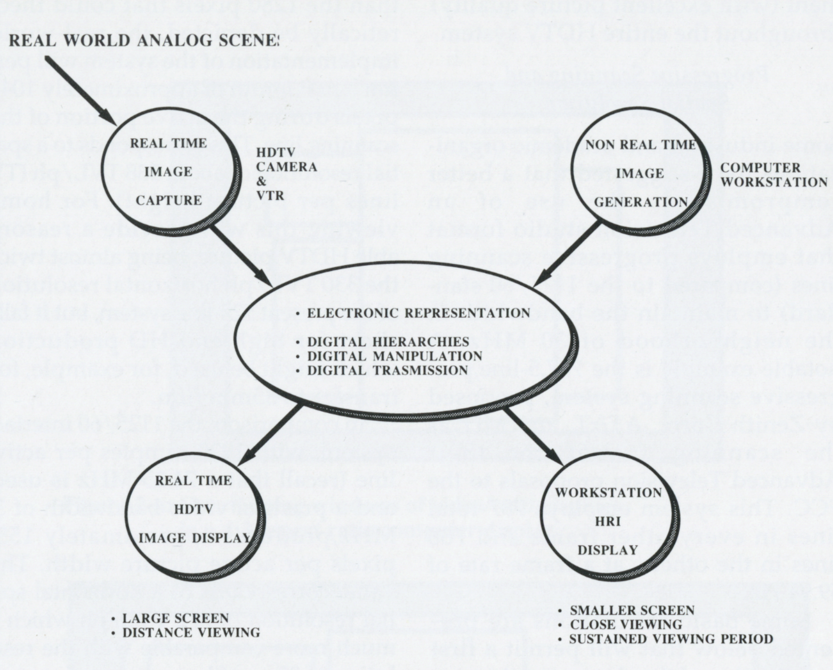

Figure 1: Convergence between HDTV and High Resolution Imaging can be found at the level of their respective digital representations

Hence, HDTV displays call for much larger and wider screens (than those in use today) if the full psychophysical impact of the HDTV display is to be properly realized. To better exercise the human visual system calls for viewing the large screen from a distance considerably greater than that of the computer display. The clear distinction in viewing environments sets sharply different design criteria for the two scanning systems that are required to separately optimize each. In particular, HDTV monitors and receivers (at the recommended 3 times picture height viewing distance) comfortably accommodate interlace scanning for psychophysically adequate viewing. At this distance, for instance, the scanning structure becomes essentially invisible.

Furthermore, interlace scanning in HDTV entails much more than mere considerations of the display. It is a pivotal design decision at the very front end of the system — the television camera. This highly complex opto-electronic transducer that is so central to all that is television has no counterpart in computer generated imagery.

More than any other parameter circumscribing the acquisition of television images, sensitivity remains the single greatest challenge to the camera and optical manufacturers. Sensitivity has never been high enough in contemporary 525/625 cameras to adequately satisfy program producers. The HDTV camera's challenge is even greater, because of the inherent sensitivity loss incurred by use of a wider aspect ratio and greater system bandwidths. The further loss of sensitivity (in today's state-of-the-art HD CCD sensors) by the use of progressive scanning is simply not acceptable to program producers in the television or motion picture industry (sensitivity is tightly linked to picture depth of field — a critical creative dimension to HD picture making).

Until radically improved imager technology finally evolves, interlaced scanning remains a powerful expedient in spatio-temporal subsampling, allowing the design of a television system that ensures camera designs that properly function in the real world. This is even more true with the newly introduced HD CCD camera than with the older HD pickup tube camera implementations[3-4].

Furthermore, for those who advocate the use of a progressive scanning structure through the entire HDTV chain (while maintaining a high line number, such as in the 1125/60 HDTV system), the additional hardware complexities and cost penalties in handling the substantially wider bandwidth (60 MHz instead of 30 MHz per RGB channel) must be added to the loss of sensitivity in the camera. Interlace scanning allows the substantial reduction in bandwidth critical for the implementation of practical equip-

ment (with excellent picture quality) throughout the entire HDTV system.

Progressive Scanning and Spatial Resolution

Some industrial and academic organizations have suggested that a better compromise is the use of an Advanced Television studio format that employs progressive scanning lines (compared to the 1125/60 standard) to maintain the bandwidth in the neighborhood of 30 MHz. A notable example is the 787.5-line,progressive scanning system, proposed by Zenith Corp., AT&T, and MIT as the scanning format for their Advanced Television proposals to the FCC. This system employs 787 total lines in every other frame and 788 lines in the others, at a frame rate of 59.94 Hz.

Some basic calculations are presented below that will permit a first examination of the chosen spatio-temporal compromise of the 787.5-line system.

The active picture raster specified by this system calls for 1280 pixels per active line time and 720 active picture lines. Hence, the active area of a frame consists of 1280 x 720 = 921,600 pixels. However, the exact meaning of the term "picture resolution" cannot be determined solely by considerations of pixel density. The important specification of available video bandwidth must also be taken into account. System bandwidth in turn, depends on the sampling frequency selected for digital processing in the system and, most importantly, on the filtering characteristics of the antialiasing filters (for luminance and color-difference signals prior to A/D conversion).

The 787.5-line system utilizes a sampling frequency of 75.34 MHz. Since the implementation of "brickwall" filters is physically impossible, the "Nyquist Bandwidth" of 75.34/2 MHz = 37.67 MHz remains simply as a theoretical upper limit. Practical design rules for the realization of A/D circuits suggest a "Filter Factor" of about 2.45, which enables the implementation of fast frequency roll-offs without generation of objectionable "spatial ringing" in the picture.

Hence, the usable bandwidth — for display — of the 787.5-line format will be approximately 75.34/2.45 MHz = 30.75 MHz, a system bandwidth of almost 31 MHz. This value represents 81.62 % of the theoretical upper bound that could be handled by the ideal system. This also indicates that rather than the 1280 pixels that could theoretically be depicted, the real-world implementation of the system will permit a maximum of approximately 1045 pixels during the active portion of the scanning line. This corresponds to a spatial resolution of about 588 TVL/ph (TV lines per picture height). For home viewing this will provide a reasonable HDTV picture, being almost twice the 330 TVL/ph horizontal resolution of the present 525-line system, but it falls short for high-end HD production which might be used, for example, for transfer to 35mm film.

In comparison, the 1125/60 interlace system, with 1920 samples per active line (recall that a 74.25 MHz is used) and a practical video bandwidth of 30 MHz,produces approximately 1552 pixels per active picture width. This value corresponds to a horizontal spatial resolution of 872 TVL/ph which is much more comparable with the resolution of 35mm film.

As can be observed from these calculations, there exists a considerable performance tradeoff in the spatio-temporal characteristics of these two HDTV studio formats. In the case of the 787.5-line format, the decision is made to maintain temporal resolution by the use of progressive scanning, introducing, however, a substantial reduction of spatial resolution. For the 1125/60 system, the use of interlace scanning affords a high overall spatial resolution with a small sacrifice in vertical resolution. Interlace scanning nevertheless has a high 60Hz temporal capture rate — due to the physical characteristics of the scanning process in television cameras (with either pick-up tubes or CCDs)[5].

It should be mentioned also that the effects of the so-called "Kell factor" (used by some to argue that the vertical resolution of the 1125/60 system is only about 750 lines, rather than 1035 lines) apply equally to both interlace and progressive scanning though a second factor does effect interlace scanning. These factors are primarily a "display" phenomena. The HD camera and the videotape recorder actually capture considerably more information with virtually all 1035 vertical samples contributing.

The HD Digital VTR

The high spatial resolution of SMPTE 240M is essential for a high-end high definition production standard that will contribute to motion picture production and post-production in addition to servicing important industrial imaging applications. This spatial information, once stored in digital form by the recording process of the digital 1125/60 HDTV tape recorder, can be used for complex opto-electronic processes such as film-to-video and video-to-film transfers. In these cases, the maximum spatial information is vital for successful, seamless intercuts.

The very existence of this 1.2 Gbps digital 1125/60 HDTV tape recorder represents the state-of-the-art in HDTV recording technologies — from the point of view of high speed digital signal processing, servomechanisms, new materials for recording and playback heads, metal particle tape for increased recording densities, error correction/concealment, recording wavelength, reliability, etc. At present there are no technologies that can result in the production, on a commercial basis, of a digital HDTV recorder capable of recording in excess of the 2 Gbps, required for an HDTV production format with over 1000 lines and progressive scanning at a high 60 frames/sec.

The HD Display Monitor for High Resolution Graphics

When discussing the suitability of the 1125/60 HDTV studio format (as well as any other proposed ATV format) to applications requiring interfacing to high resolution computer workstations, one must consider the current defacto picture raster format is 1280 x 1024, using progressive scan and an aspect ratio of 5:4.

It is highly likely that, if market conditions require it, a 16:9, progressive scan, 1125-line monitor will appear for the computer display market. Despite the technical differences between presentation devices for "widescreen computer displays" and monitors/receivers designed for the professional and consumer HDTV industries, it is feasible to manufacture 1125/60 HDTV interlace monitors with optional progressive scanning capability. This approach will facilitate the introduction of 1125/60 widescreen display devices for high resolution computer graphics applications by leveraging on some possible cost reductions due to the common CRTs and some circuit components.

It is believed that the availability of 1125/60 HDTV progressive scan monitors for the computer industry will serve a great deal to answer most of the system compatibility issues that have arisen from the progressive/interlace scan discussions between the com-

puter and television industries.

It should be further pointed out that an HDTV production format with a number of scanning lines less than the 1024 lines in use today will not be acceptable for many of the numerous scientific, business and industrial applications that specifically seek the highest possible spatial resolution.

The 1125/60 HDTV standard, as defined by SMPTE 240M (and separately by ATSC), contains provisions that will permit the evolution to progressive scanning when the technology becomes available.

In summary, the 1125/60 interlaced standard is, overall, the highest performance HDTV system available and its carefully chosen design parameters have allowed a very wide range of practical and reliable HD equipment to be manufactured by more than 35 international manufacturers.

THE ISSUE OF SQUARE PIXELS

The SMPTE committee spent considerable time examining the merits of a proposal quite new to the television industry — the square pixel.

Originally proposed by representatives from the graphics industry, the existence of square pixels, i.e., an orthogonal sampling grid with equal spacing horizontally and vertically, although a desirable feature for low-end computer graphics systems (due to the fact that simple software tools can be used to ease hardware demands for still-image manipulation), need not be a requirement for more complex graphics and image processing terminals.

The latter point has been demonstrated universally in post production settings for quite some time with the commercial availability of sophisticated computer graphics and special effects generators for 4:2:2 pictures in the 525/625-line studio component world (which by definition do not have square pixels), and, more recently, by similar equipment showing the same versatility in image manipulation utilizing the 1125/60 HDTV format.

The committee was confronted with the following facts:

• The 1035 active lines of 1125/60 HDTV system were already specified in SMPTE-240M to facilitate the downconversion to 525- and 625-line television systems (an issue of scalability important to the television industry). It should be mentioned that a 1990 ATSC proposal for possible modification of the 1125/60 HDTV standard to accommodate 1080 active

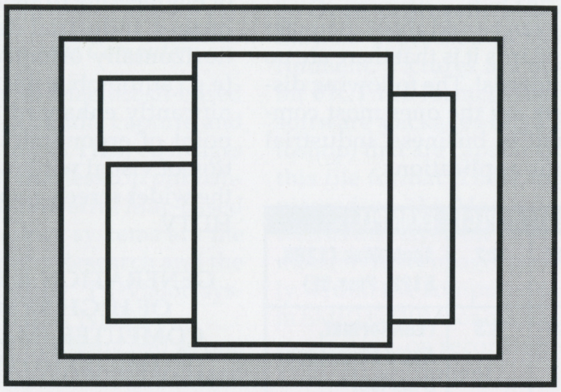

Figure 2-a: Overlapping windows of video/text/graphics in a 4:3 aspect ratio computer display

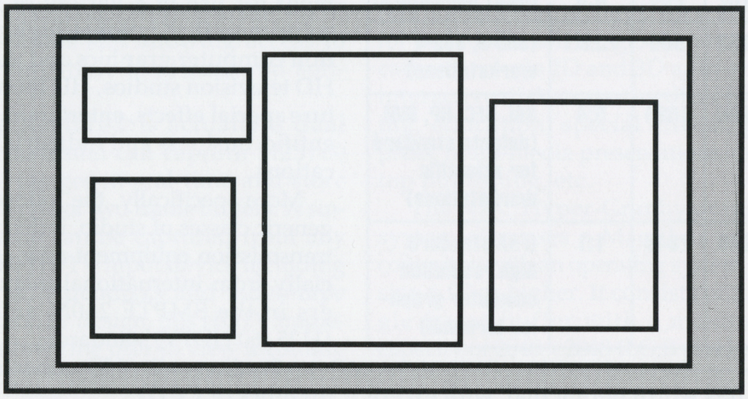

Figure 2-b: Windows of video/text/graphics in a 16:9 HDTV computer display

lines — giving rise to a 1920 x 1080 square pixels digital raster — was rejected by some in the computer industry (and academia) and precluded the development of a unified specific U.S. position in the CCIR[6].

• The number of 1920 active pixels was highly attractive because of the hierarchical relationship with CCIR Rec. 601 (which would facilitate easy downconversion to 525/625 systems).

• The new picture aspect ratio for HDTV was internationally agreed to be 16:9.

These parameters give rise to pixels with an aspect ratio of:

$$(1920/1035) \times (9/16) = 1.043$$

or 4.3% deviation from perfect squareness.

This value should be compared to the 11.8% and 6.5% deviation values of 525 and 625-line 4:2:2 systems respectively. Notice further, that even such deviations from perfect square pixels do not affect the software and hardware calculations that have to be performed when executing spatial image manipulations, since, in most cases, the scaling factors are incorporated in the numerical factors used in the 2-D and 3-D rendering algorithms. Also, "rectangular pixels" do not hinder in any way the use of sophisticated graphics terminals, paint stations, digital special effects, storage and switching devices. Furthermore, in the development of standards for bit-rate reduction of conventional and advanced television, for intra/ interplant contribution and consumer delivery, most implementations make use of digital rasters with non-square pixels. As will be shown below, there is already a wide range of HDTV/HRI systems in use in diverse industries — despite the non-square pixels of SMPTE 240M.

ADVANTAGES OF THE WIDESCREEN 1125 HDTV DISPLAY FORMAT

If something can be said about computer display standards it is that there are no unified standards! The following display formats are the ones most commonly found in business, industrial and scientific applications

WIDTH	HEIGHT	ASPECT	EXAMPLE
512	342	3:2	Apple Mac (128K, 512K, Plus,SE)
640	480	4:3	(VGA format, Apple Macintosh II series)
1024	768	3:2	(Super VGA, Sun 386i)
1152	864	4:3	(NeXT computers)
1152	900	1.28:1	(Sun-3, Sun-4 workstations)
1280	1024	5:4	SGI, DEC, HP, IBM (defacto standard for scientific workstations)
2048	2048	1:1	(FAA standard high resolution computer graphics terminal)

It is worth noting that, with exception of the 2048 x 2048 display format (one-to-one CRT aspect ratio), all the other formats employ CRTs with aspect ratios established by the television industry, that is, a 4:3 screen aspect ratio. Inside this display area, computer manufacturers adjust the display height and width to achieve the intended picture aspect ratio. It should be mentioned, however, that with the advent of more complex "computer operating systems", with increasing capabilities for handling multiple processes simultaneously, a wider screen geometry is becoming increasingly desirable for many multi-window presentations.

In 4:3 displays, the use of multiple windows of adequate size for at least a minimum understanding of the visual presentation, implies various degrees of occlusion of the image data, which often makes the display of complete windows, side by side, difficult (see figure 2-a).

The picture aspect ratio of HDTV is 16:9 (see figure 2-b). In other words, a more rectangular or "landscape" type of display geometry, allowing the presentation, for example, of two A4 size documents side by side. Also, industrial applications of high resolution computer graphics such as presentation of engineering drawings, CAD/CAM images, industrial designs that favor horizontally oriented image objects (e.g., automobile design), etc, are significantly enhanced (from the viewpoint of ergonomics and manipulation of visual windows) by the use of the wider screen geometry offered by HDTV.

GENERATION & PROCESSING OF HIGH RESOLUTION COMPUTER IMAGERY WITH THE 1125 HDTV SYSTEM

Business and Industrial Applications

There is in existence an extensive list of professional 1125/60 HDTV equipment for use in a variety of system solutions (that involve high resolution computer graphics and video) in HD television studios, HD motion picture special effects, entertainment, scientific, business and industrial applications.

More specifically, the following are generic classes of studio, industrial and transmission equipment now commercially from international manufacturers in the SMPTE 240M and 260M (1125/60 HDTV) standards:

- Studio quality HD cameras (pick-up tubes or CCD)
- High resolution still cameras (for scientific and industrial use)
- Digital HD videotape recorders (reel-to-reel)
- Digital and analog HD video cassette recorders
- Digital and analog HD video switchers
- Digital video effects generators/processors
- Desktop scanners and printers
- Digital storage media (CD-ROM, Magneto Optical, Hard Disks, DAT)
- Industrial and professional HD monitors and receivers
- Front and rear-projection systems
- HD Telecines
- 2D and 3D HD digital graphics/imaging computer workstations
- HD Paint systems
- Single and multi-frame frame-grabbers
- Computer-HDTV standards converters
- Matting and Keying devices
- Digital and analog routing switchers, distribution amplifiers
- Digital Codecs and digital/analog fiber-based transmission systems
- Test equipment

Recording High Resolution Images

Very high resolution images generated by computers are presently being used for the creation of stills, animation sequences, data visualization, etc. These images, in many instances, are today making use of the capabilities of the 1125/60 HDTV system for large-screen display presentations, long-term archiving, digital editing and post-production, HDTV-to-film transfers, digital real-time HD transmission, electronic cinemas, etc. To achieve this, the computer output data is made to conform to the scanning and raster structure of the SMPTE 240M standard.

The recording of these high resolution images can be accomplished by the use of, for example, a 1.2 Gbps real-time HD digital tape recorder, which fully complies with all the digital parameters of the 1125/60 HDTV standard. To help the interfacing of computer images and the HD digital tape recorder, several vendors have introduced HD frame buffers which can solve the problem of the non real-time transfer of the computer data vs the real-time operation of the digital HD recorder.

HDTV Multiframe Framestores

Toshiba Corp.'s advanced HD Frame Buffer, the TFS-800, a computer/HDTV product, is configured to store from 12 up to 240 frames of HD 1125/60 video (current product offers a maximum capacity of 72 frames). It accepts analog or digital Y, P_B, P_R component signals fully complying to the specifications of SMPTE 240M. It also offers a SCSI computer data port for non-real time bi-directional transfers of image data with high resolution imaging workstations. Furthermore, the device offers a number of special playback modes for dynamic analysis of the stored images.

Sony's HDDF-500 Frame recorder can operate with either R, G, B or Y, P_B, P_R input signals and utilize dynamic RAM memory to capture images from real-time analog and digital HDTV sources. It has a storage capacity of up to 32 frames (or 64 fields) and can be controlled like an HD digital videotape recorder by conventional TV editors or by computer commands (via an RS-422 interface) for remote operation. The HDDF-500 also has capabilities for single or multiple field/frame (endless loop) recording and playback.

To facilitate the integration of the

HDDF-500 to image processing systems, the HDDF-500 makes use of two kinds of computer data connections: SCSI-1 and DVR11-W (DEC). Both interfaces allow the transfer of 1125/60 HDTV images to and from the host computer and the video memories in non-real time (see figure 3). Both of these interface protocols support partial or full frame transfers and various control functions including field/frame selection and frame(s) capture.

Multiple high resolution images satisfying the 1125/60 digital HDTV standard can be rendered and transferred in non real-time to the HDDF-500, which in turn (once it receives 32 frames) can download all its images, in real-time, to the 1.2 Gbps digital HD videotape recorder. This "32 frame edit" not only expedites the creation of animation sequences, but also greatly reduces the wear sustained by the recording heads when otherwise performing edits of single images (frames). Since the entire process can be automated easily, enabling overnight, non-supervised rendering and recording, this represents an enormous saving in time and operator costs in the creation of long sequences of animated sequences or high resolution special effects.

In essence, these various HD multi-frame frame grabbers become an ideal "bridge" for linking the worlds of high resolution image processing workstations and HDTV.

HDTV and the Mac Computers

The availability of Macintosh-based products that can handle capture and software processing of 1125/60 images is significant for the desktop publishing market. Two powerful Mac-based 1125 HDTV graphics systems are the "ReStore®" of Rebo Research and the "NAC Hyper-Graphy" Hi-Vision system manufactured by NAC.

The ReStore® was launched as one of the first personal computer-based 1125/60 HDTV framestores for manipulation and storage of HDTV images. It is designed to operate with a Macintosh II® computer as its host/controller. Its chassis plugs into the Mac II via a NuBus slot allowing access to Mac compatible hardware and software.

The ReStore® is actually a dual framestore that can capture 1125/60 HDTV images in real-time and store them in one of two frame buffers. A single frame can be captured from any 1125/60 HDTV input device including cameras, videodisks and video-tape recorders. By design, this HDTV framestore allows the user to view incoming video or the contents of either frame buffer. These functions are all controlled via the Mac II interface.

Once captured, 1125/60 images may be processed in the Mac environment. Pictures are stored in a 24 bit PICT file format. There are many software packages (e.g., Adobe Photoshop) that are capable of supporting this file format. These images can be viewed on the Mac color screen as well as displayed on an 1125/60 HDTV monitor. Also, images generated entirely within the computer can be output in SMPTE 240M for display and further processing or recording by external 1125/60 equipment.

The ReStore® also has capabilities for full color and gamma correction by means of built-in color look-up tables, which enables the device to function as a high quality color corrector for high definition images. Other applications include 2D and 3D animation, interactive disk usage, medical imaging, education, special effects, prepress, multi-media presentations, desktop publishing, etc.

The NAC Hyper-Graphy graphics system also uses a Mac II as a host computer, with an operating system version 6.07 or higher. It consists of a single frame buffer with a maximum capacity of 2048 x 2048 R,G,B pixels. For

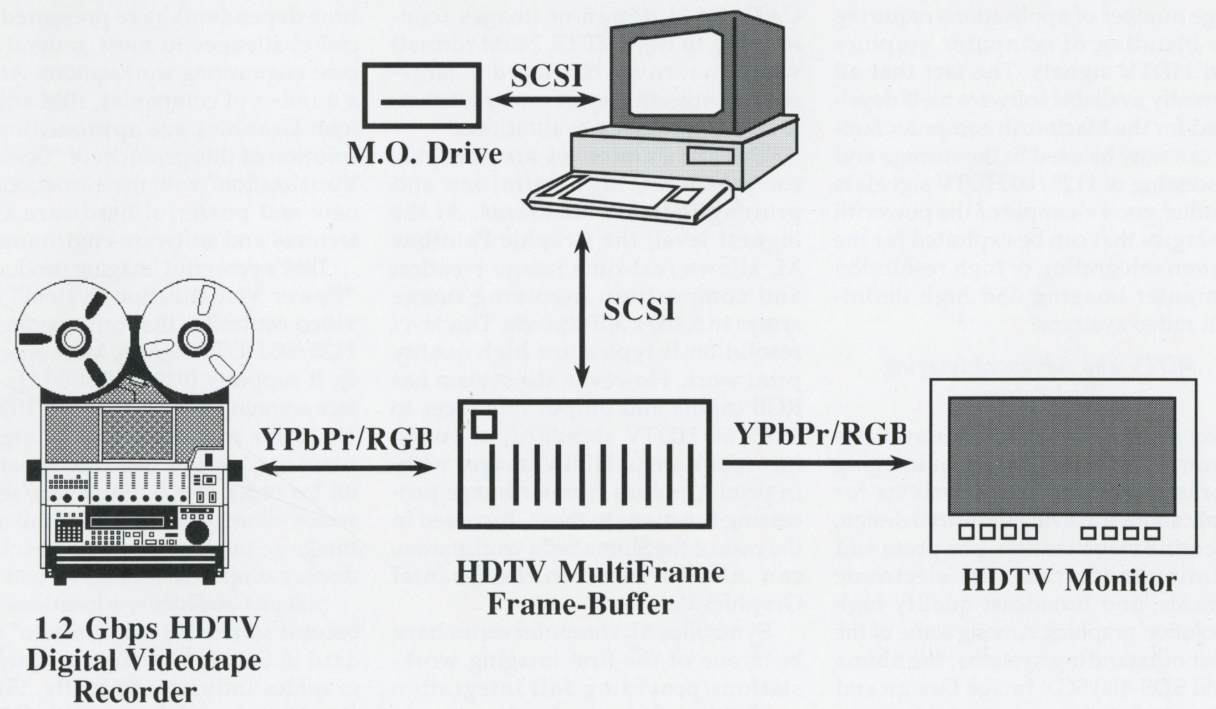

Figure 3: HDTV MultiFrame-Buffer application - High Resolution Computer Graphics Animation

display purposes the user can select between 8, 16, and 24 bits per pixel.

The NAC Hyper-Graphy system fully complies with the digital parameters of the 1125/60 HDTV system. It can also operate in other raster formats that result in close clock frequencies to those used by the 1126/60 format. In particular, besides the standard of 1920 x 1035 active pixels called for by SMPTE 260M, the system can work at 1840 x 1035 square pixels in interlace, 16:9 aspect ratio, 60 Hz mode. It also works at 1152 x 864 square pixels, progressive scanning, 4:3 aspect ratio, 60 Hz mode.

This single-frame, high resolution graphics system employs a single NuBus interface card for communication with its host computer. It is also capable of accepting real-time input signals from 1125/60 HDTV professional equipment as well as non real-time images from 35mm film slide scanner and Flat bed image scanners through interface board options. As mentioned above, the system can output video signals in the SMPTE 240M format for storage and manipulation by 1125/60 equipment, as well as accommodating a number of other picture raster formats for compatibility with current imaging workstations.

As in the case of the ReStore® system, the NAC Hypher-Graphy high resolution system can be used in a large number of applications requiring the blending of computer graphics and HDTV signals. The fact that all currently available software tools developed for the Macintosh computer family can now be used in the storage and processing of 1125/60 HDTV signals is another good example of the powerful synergies that can be exploited for the system integration of high resolution computer imaging and high definition video systems.

HDTV and Advanced Imaging Workstations

Several companies have made available a number of high resolution imaging workstations and paint systems for applications involving industrial design, scientific visualization, pre-press and printing industries, film electronic opticals, and broadcast quality high resolution graphics. Among some of the most outstanding systems: the Shima Seiki SDS-480 SGX Image Design and Retouching System, the Graphic Paintbox XL from Quantel, Inc., the PowerVision Series of graphics supercomputers from Silicon Graphics, Symbolics XL1200 workstations and the IBM AIX® Visualization Data Explorer/6000.

The Shima Seiki SDS-480 system uses a large number of microprocessors for ultra high-speed distributed data processing. This technology permits very high-speed drawing and rendering of 1125/60 images. The system works 24 bit per color pixel with a maximum resolution of 8,000 x 8,000 pixels for retouch work. A masking function allows cutting and pasting, as well as coloring and image synthesis, to be conducted in real time. For screen composition, the composition ratio, position and angle can be instantly established. A shading function eliminates unnatural overlapping of sections, providing realistic high-level composition with natural appearance.

The Shima Seiki paint system also includes functions such as pen strokes with watercolor, air brush, chalk and marker effects and real-time texture mapping, which allows characters and patterns to conform to the contours of any line. Built-in affine conversion functions allows enlargement, reduction, rotations and perspective of the 1125/60 HDTV image in real-time. These features facilitate the use of the Shima Seiki Image Design and Retouching system in business and industrial design applications. This is exemplified by the use of this workstation in the automobile industry, for real-time CAD/CAM design of images (conforming to the SMPTE 240M format) which in turn are displayed in large-screen projection systems for aesthetic and engineering evaluations.

Quantel Paintboxes are available for broadcast, high definition and printing industry standards. At the highest level, the Graphic Paintbox XL allows real-time image creation and composition involving image arrays to 5,400 x 3,700 pixels. This level resolution is typical for high quality print work. However, the system has RGB inputs and output interfaces to 1125/60 HDTV standard, allowing incorporation of HDTV images within print graphics. Similar image processing functions to those discussed in the case of the Shima Seiki workstation, can also be found in the Quantel Graphics Paintbox.

Symbolics XL computer series have been one of the first imaging workstations providing full integration capabilities with professional equipment in the 1125/60 HDTV format. Their "Frame Thrower" video/graphics processor brings high performance, real-time graphics and video I/O to this workstation with a flexible architecture supporting image resolutions from conventional to High Definition television.

The Symbolics hardware/software system offers modelling and scripting tools that significantly reduce production time for 3D and 2D high resolution video animations. For example, Symbolics' S-Geometry — a 3D modelling software module — supports interactive design and sculpturing of 3D shapes for illustration, animated sequences and construction of flexible objects for displacement animation. The S-Dynamics software tool designs complex animation with control of virtually anything that changes over time, like appearance, shape and motion. S-Render converts 3D shapes and dynamics control information into sequences of realistic images at variable resolutions.

An important feature of the Symbolics XL1200 workstation is its interfacing capability for transferring SMPTE 240M images to and from existing HD multiframe frame buffers for non-supervised rendering and recording of 1125/60 HDTV animation sequences.

Over the past few years a number of organizations have worked on solving the myriad problems of converting physical data from a host of disparate sources into 3D objects and colors on a CRT. Very complex data sets (multiparameter, multidimensional and time dependent) have presented special challenges to most general purpose engineering workstations. Among a number of companies, IBM and Silicon Graphics are approaching the solution of this problem of "Scientific Visualization" with the introduction of new and powerful hardware architectures and software environments.

IBM's powerful imaging product, the "Power Visualization System" has a video controller that can operate with 1125/60 HDTV signals. More specifically, it supports 1920 x 1024 60 Hz interlace scanning as well as 1280 x 1024 pixels 60 Hz progressive scanning. The transfer speeds of this video controller on the order of 100 megabytes/second, which allows the delivery of full screen image sequences to a high resolution display at up to 20 frames/second.

Silicon Graphics workstations have become somewhat of a "defacto" standard in the high resolution computer graphics industry. Recently, Silicon Graphics adopted the use of the 1125/60 HDTV format, in addition to other conventional video and high resolution computer display standards (supported by their "Power Series GTX Graph-

ics") workstations, for presentation of high resolution, real-time, rendering, texture mapping and data visualization.

CONCLUSION

In the current world of conventional television systems, the evolution to the all digital implementation of equipment for studio and industrial applications is clearly well under way. The natural integration of digital video signals and their counterparts in the world of computer graphics is now seen as not only technically feasible but also giving rise to powerful new applications that make use of a harmonious blend of computer generated imagery and real-time, moving television pictures.

The only problem with the current environment is the existence of technical constraints in the form of limited color and resolution performance, which are imposed by today's video standards.

The 1125/60 digital HDTV system has been developed to serve as a video origination standard capable of supporting not only high-end program production for the entertainment and motion picture industries, but also functioning as a new high resolution, real-time, full-motion video format for numerous business, industrial and scientific applications.

Despite the non-availability of square pixels (as it is also the case for conventional television systems), the 1125/60 digital HDTV format has proven to be a versatile and advanced standard for display storage and processing of very high quality computer generated images.

The commitment by numerous manufacturers of video/image processing equipment to the digital implementation 1125/60 HDTV format and the growing number of manufacturers of computer workstations with hardware and software interfaces to this standard is the best proof that a fruitful relationship can exist between high resolution imaging and HDTV.

It is only natural to expect that the system integration that exists so successfully in the current world of personal computers and conventional video should take place at the high resolution levels of imaging workstations and HDTV. The 1125/60 digital HDTV system is indeed fast becoming the "electronic intermediate format" for the high resolution computer graphics and multimedia industries.

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